A Multi-point Vibrometer using the HHT for Signal Analysis

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What do you mean by multi-point vibrometry?

Multi-point vibrometry: The capability of *simultaneously* measuring the *time-dependent* vibration amplitude, frequency, and phase at *multiple points* on an object's surface in a non-contacting manner

Why would we need such a device?

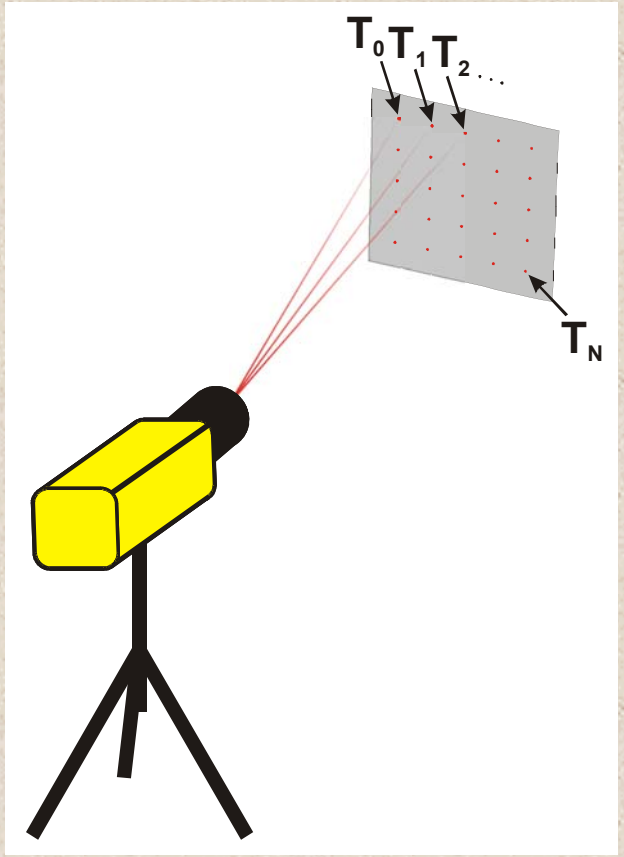
It is often helpful, or essential, to understand the global response of a structure to transient vibration phenomena:

- **Impacts or other sources of impulse loading**
- **Material fracture – crack growth or identification**
- **Global vibration suppression for structural acoustic control**

What about existing vibrometers and other vibration measurement techniques?

Existing commercially available scanning laser vibrometers *scan* over the surface and obtain measurements at discrete points, one point at a time

- No temporal coherence between measurement sites
- Vibration transients might be missed while scanning from one measurement site to the next
- Great devices for measuring steady-state vibrations

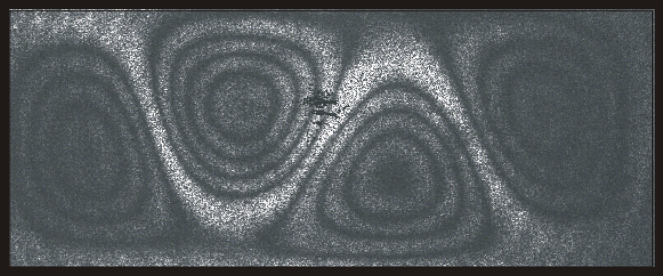


Conventional SLDV Concept

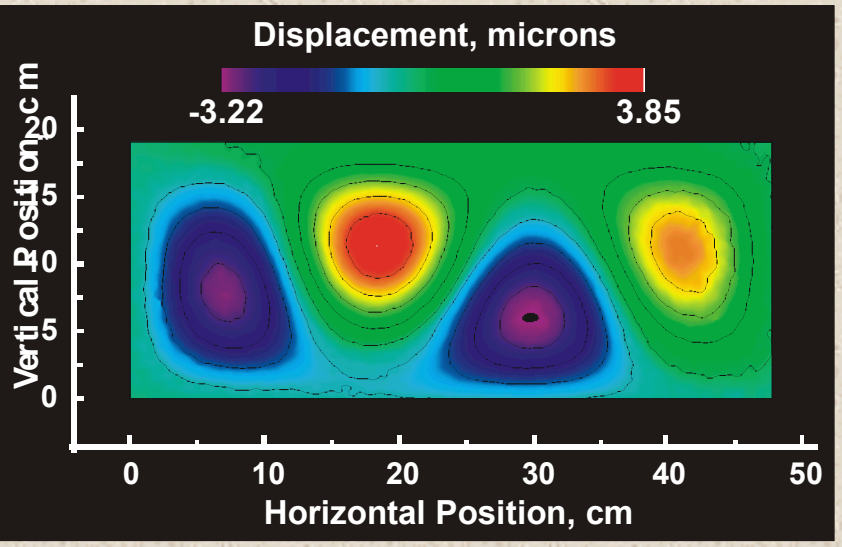
What about existing vibrometers and other vibration measurement techniques?

Electronic holography (ESPI) systems can not be used to obtain *time-dependent* vibration measurements

- **Measures static deformation or time-averaged vibration amplitude**
- **Quantitative measurements of vibration amplitude can only be obtained when the object is oscillating at a single structural mode**
- **Great full-field diagnostic technique for analyzing modal characteristics**

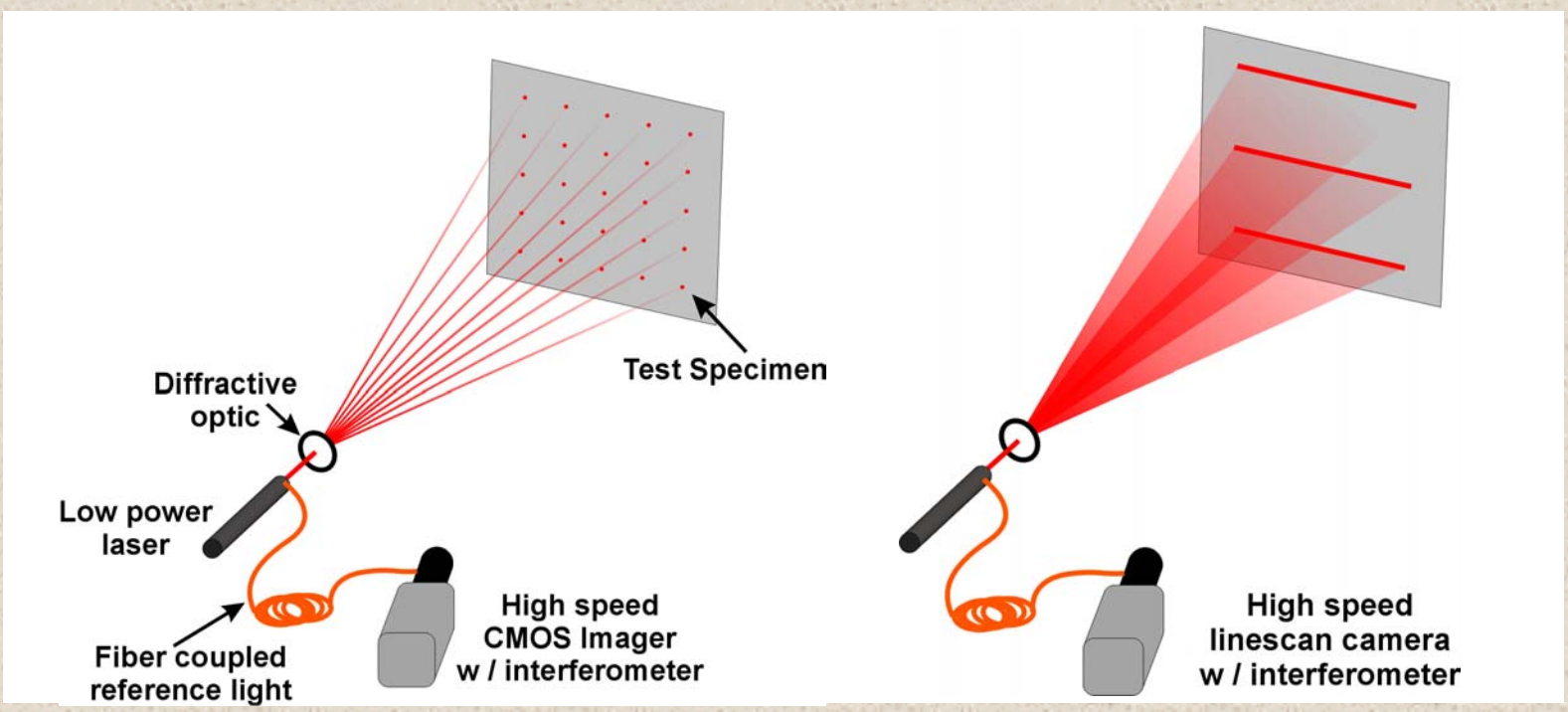


ESPI Fringe Pattern



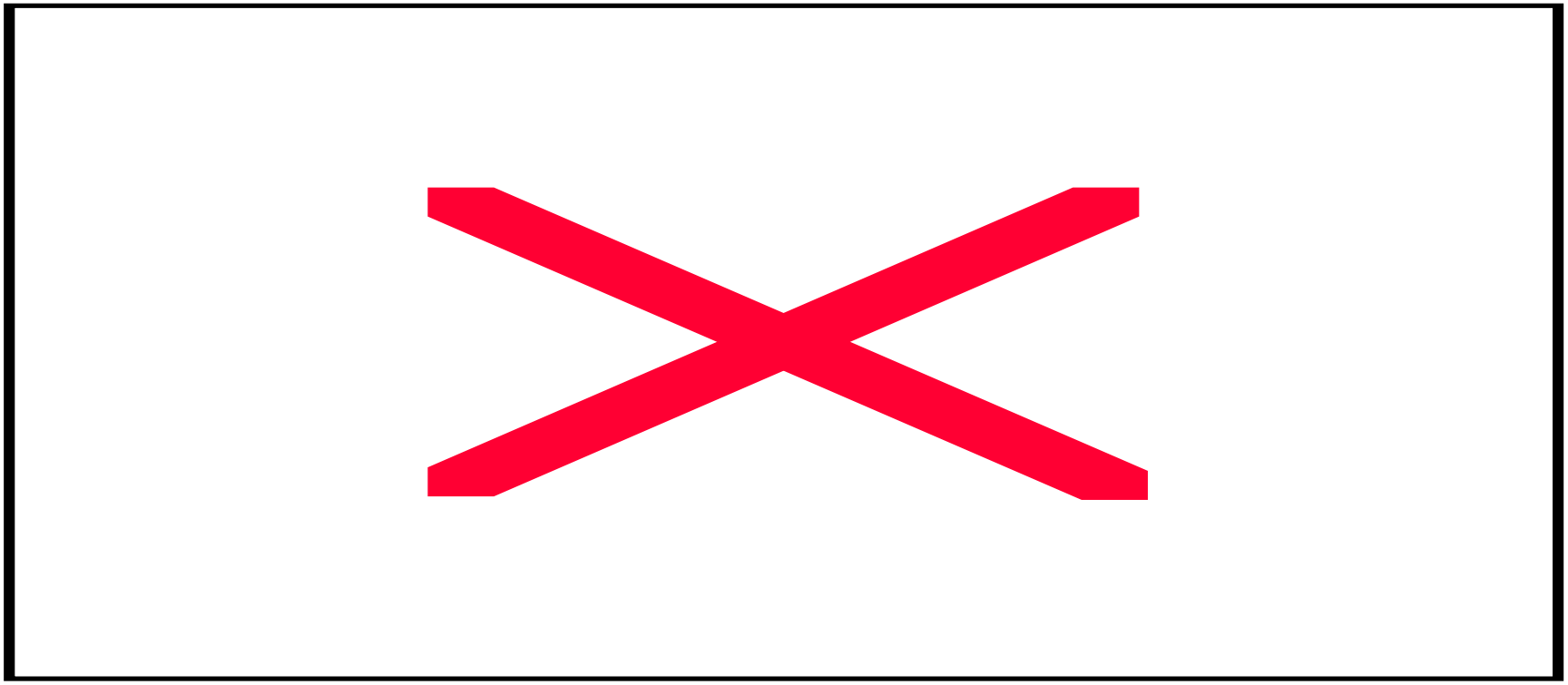
Concepts and goals for the development of a Multi-point Vibrometer

- Develop a non-contacting technique to simultaneously acquire time-dependent structural vibration data at multiple points on an object surface
- Use of diffractive optics eliminates scanning laser beam
- Latest advances in CMOS imagers, linescan cameras, and video data acquisition are used to obtain high spatial / temporal resolution



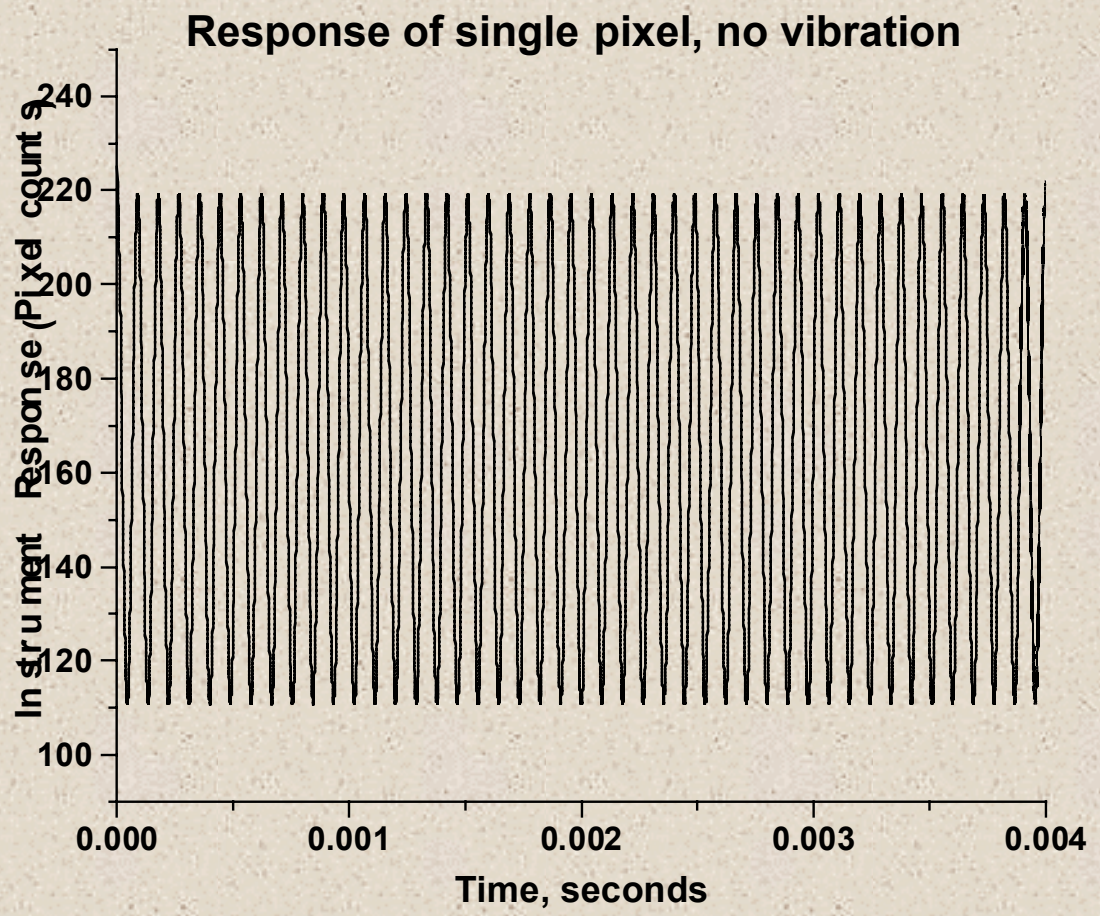
Multi-point Vibrometer Configuration

Measures time-dependent surface velocity at multiple points using Doppler effect and two tunable, synchronized Acousto-Optic Modulators (AOMs)



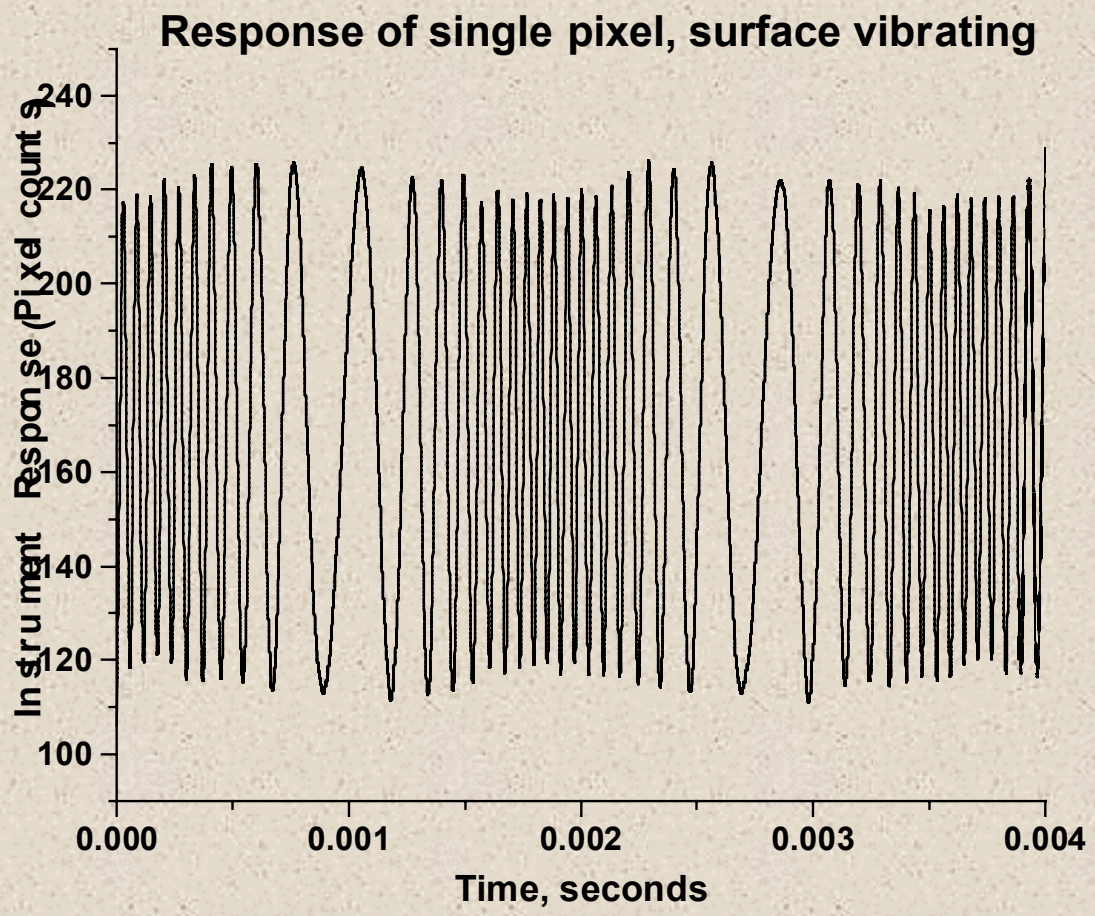
How the Multi-point Vibrometer Works:

Step 1: **Use AOMs to create interferometric beat frequency that can be time resolved by the detector**



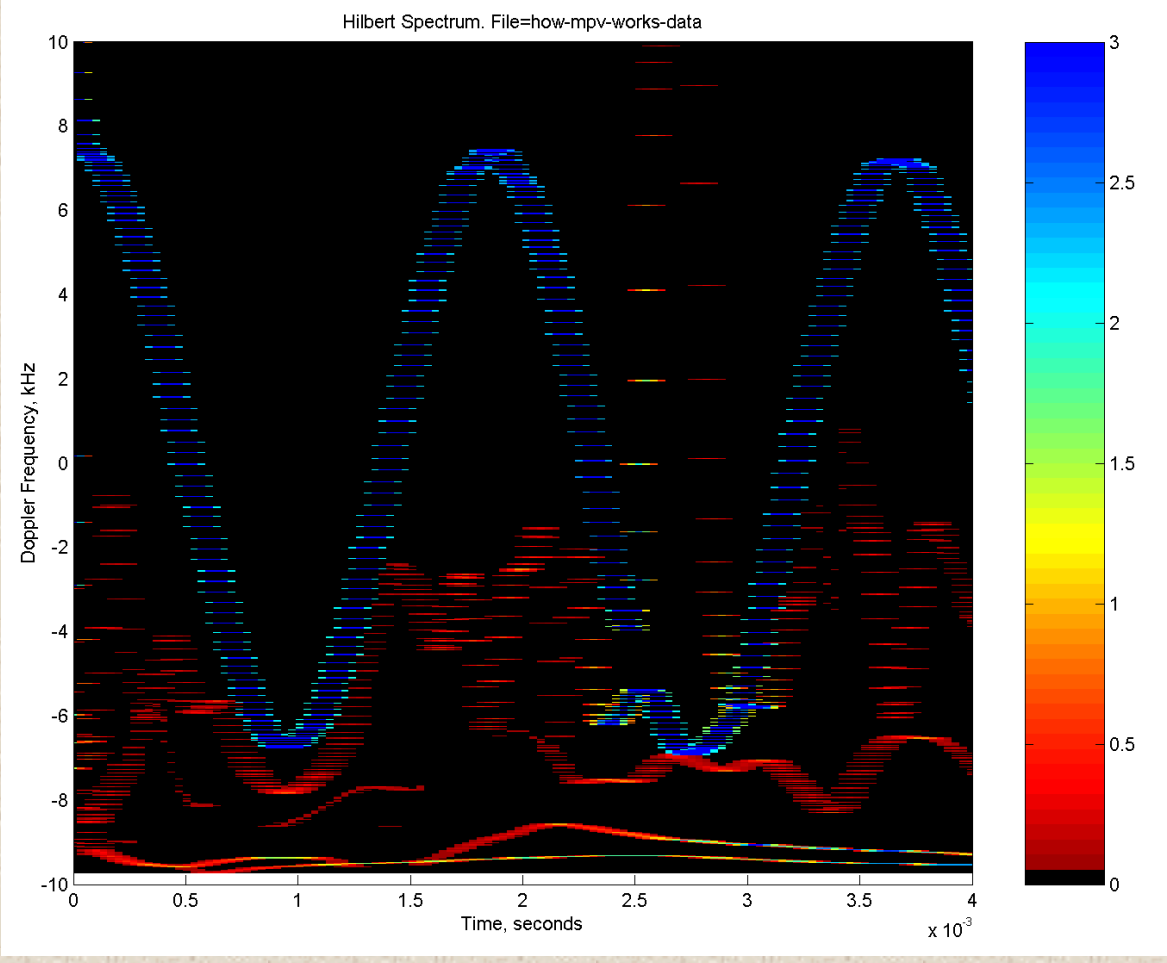
How the Multi-point Vibrometer Works:

Step 2: **Under vibration, carrier signal is frequency modulated by the associated Doppler shift**



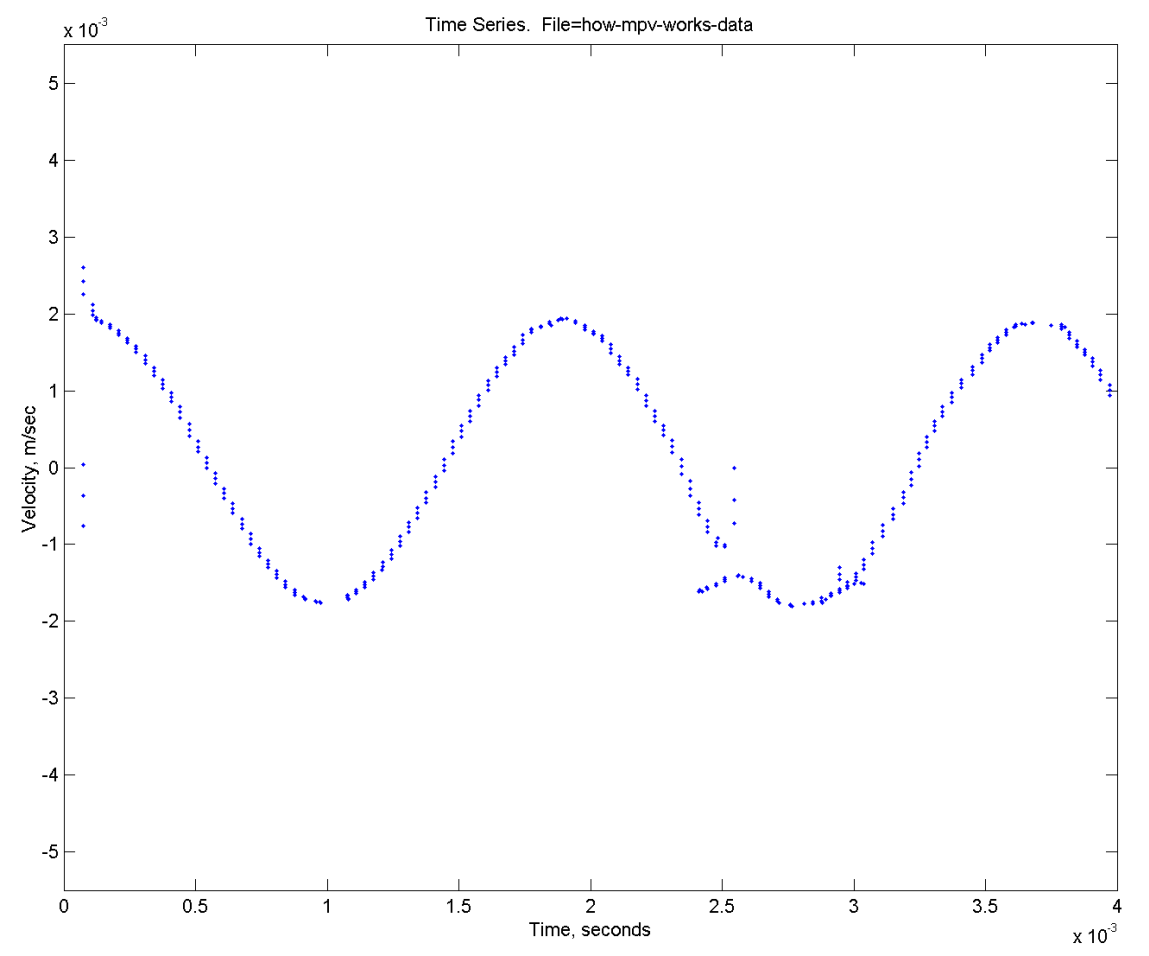
How the Multi-point Vibrometer Works:

Step 3: Perform Time-Frequency Analysis using Hilbert - Huang Transform (HHT) to determine Doppler frequency



How the Multi-point Vibrometer Works:

Step 4: **Use image processing to convert Doppler frequency to surface velocity**

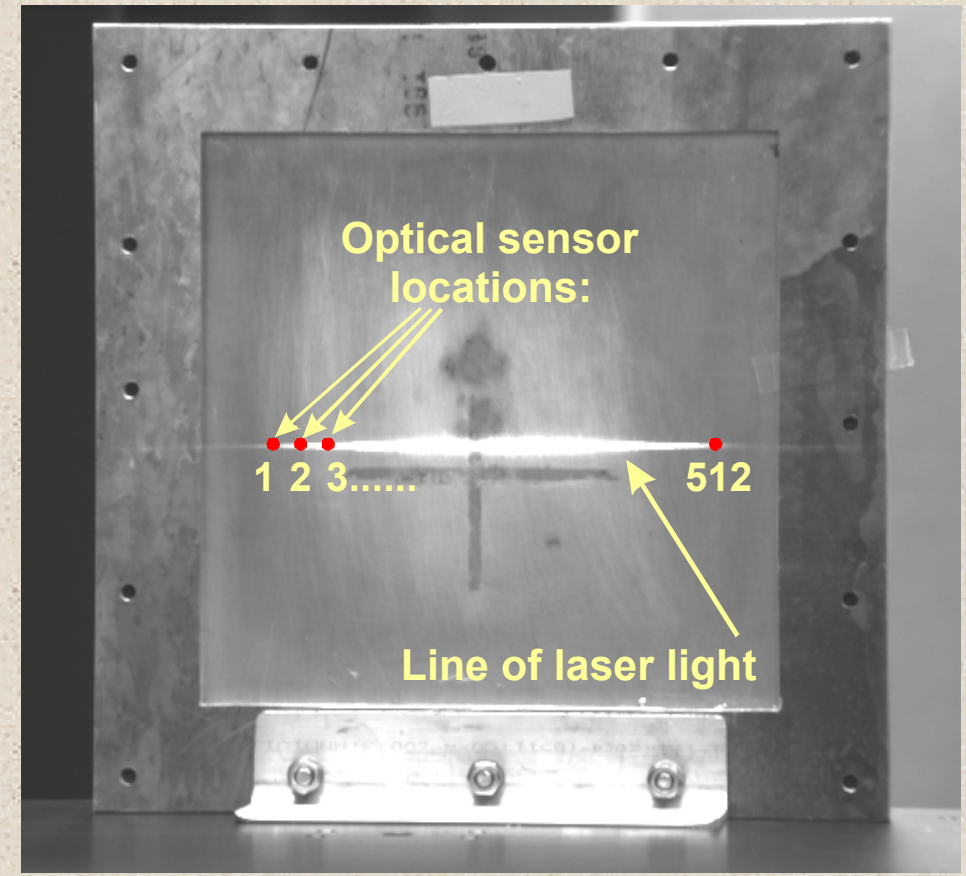


Multi-point Vibrometer Developmental Testing

Test 1: Use high speed line scan camera to obtain vibration measurements at ~512 points along a line

Objective

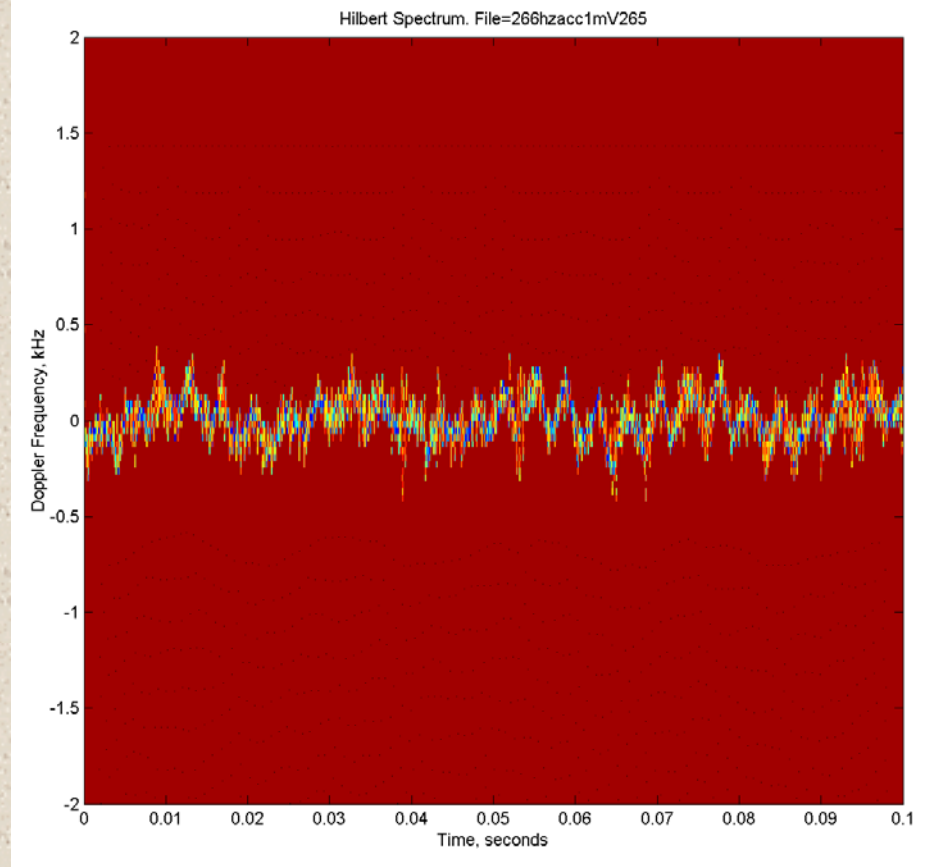
- Assess basic instrument performance
- Measurements at each detector obtained simultaneously
- Sampling rate = 90 kHz
- Test plate piezoelectrically driven at known conditions



Ability to detect changes in vibration amplitude

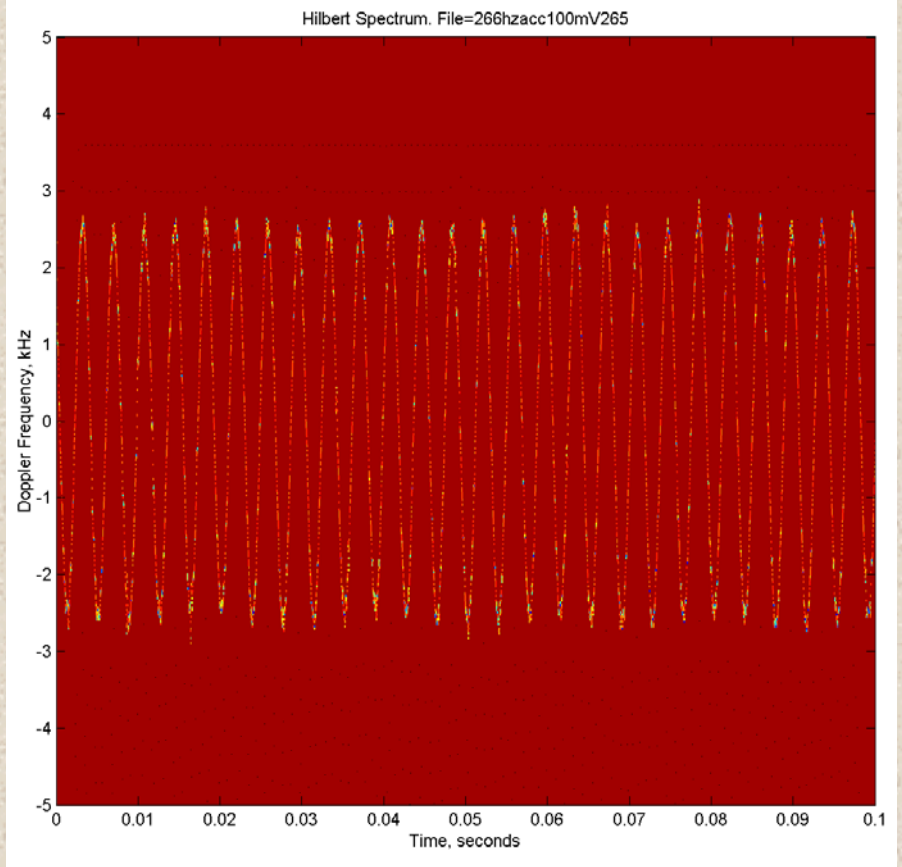
Single pixel response, sinusoidal drive signal at 266 Hz

PZT Voltage = 1 mV



Could not be resolved by accelerometer!

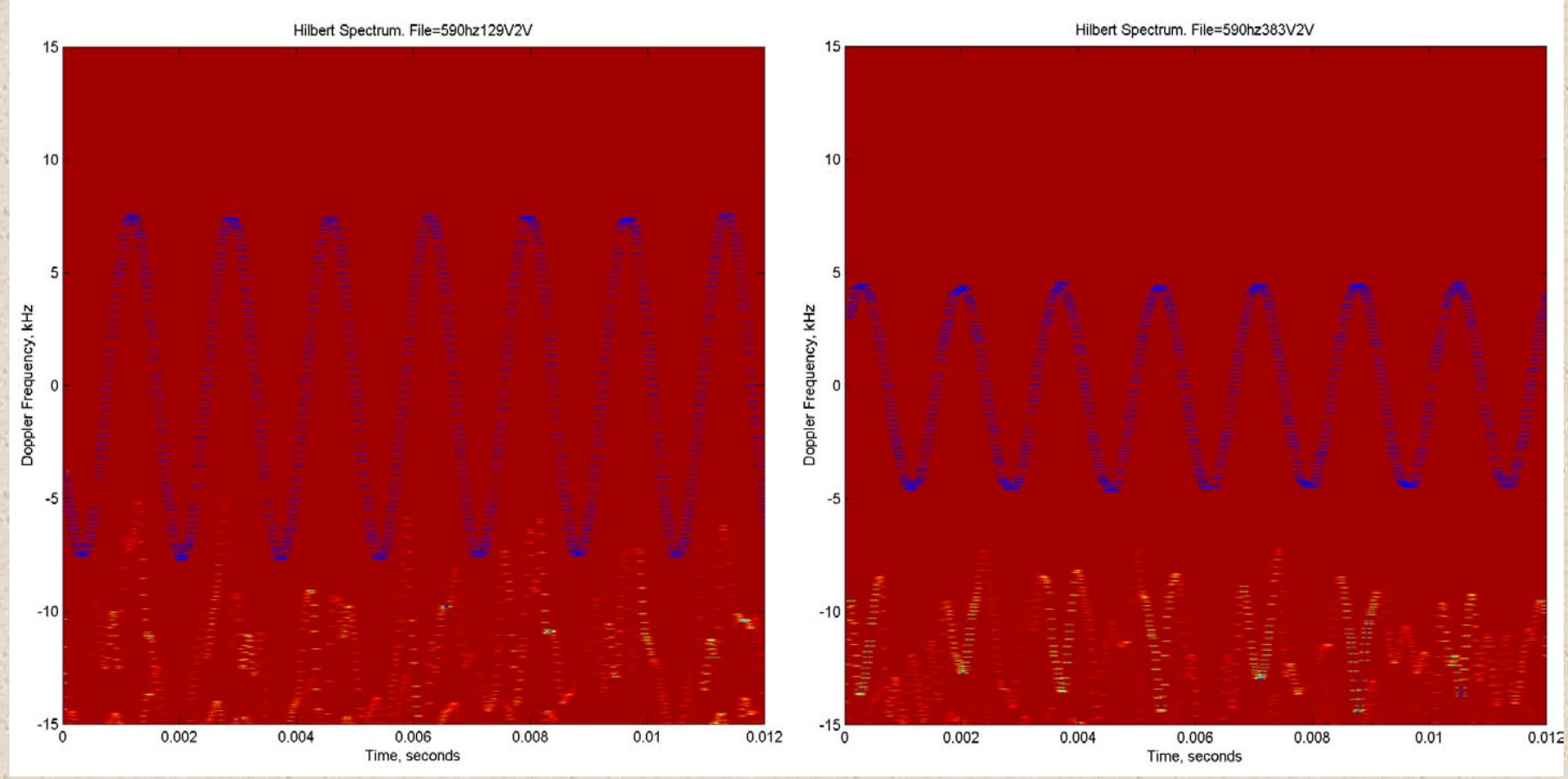
PZT Voltage = 100 mV



Typical response

Ability to detect changes in vibration phase

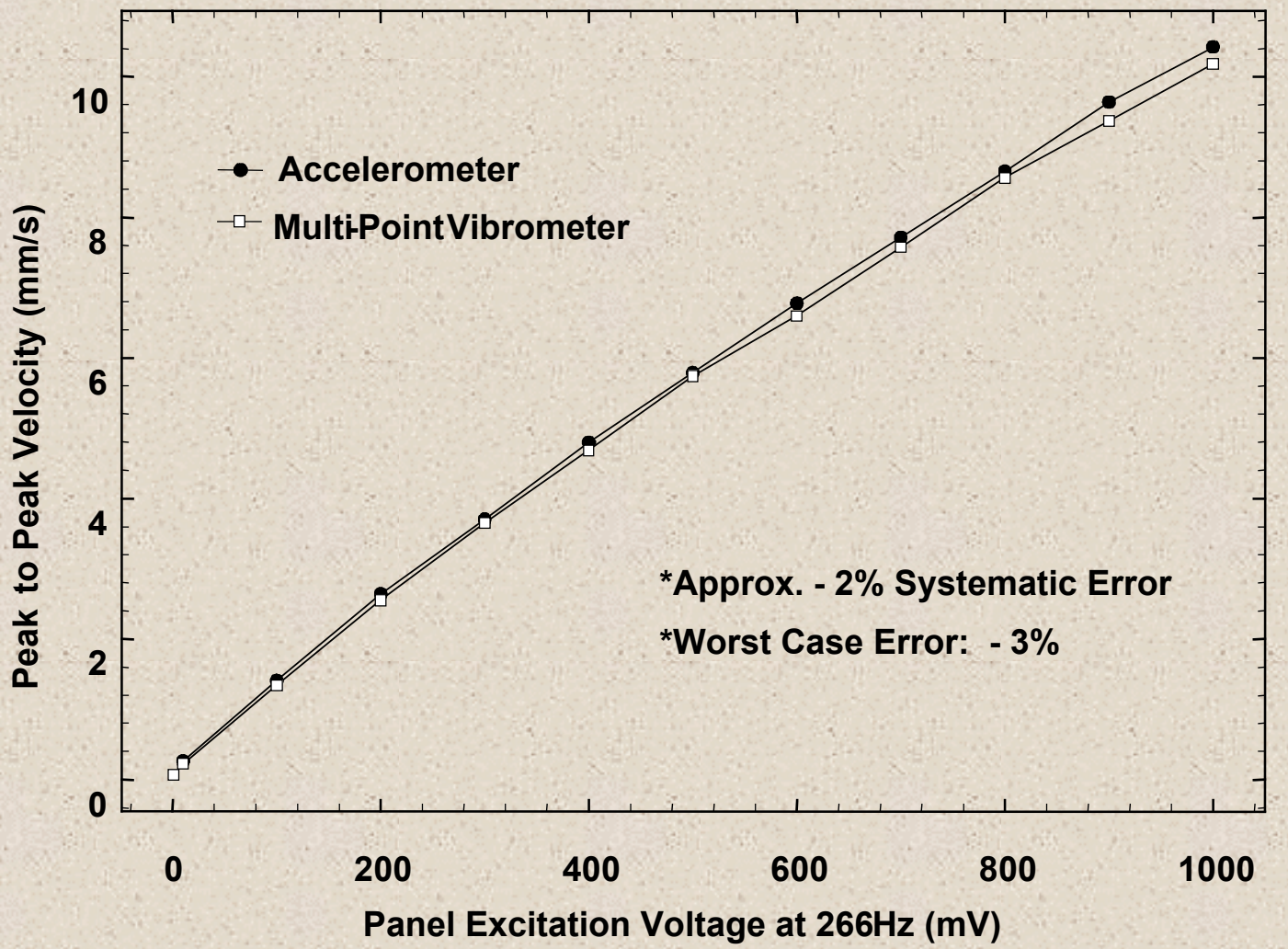
Response of two independent pixels acquired simultaneously while exciting plate in 1-x 2 mode at 590 Hz



Left side of node line

Right side of node line

Quantitative Comparison of Surface Velocity Measured with Multi-Point Vibrometer and Accelerometer

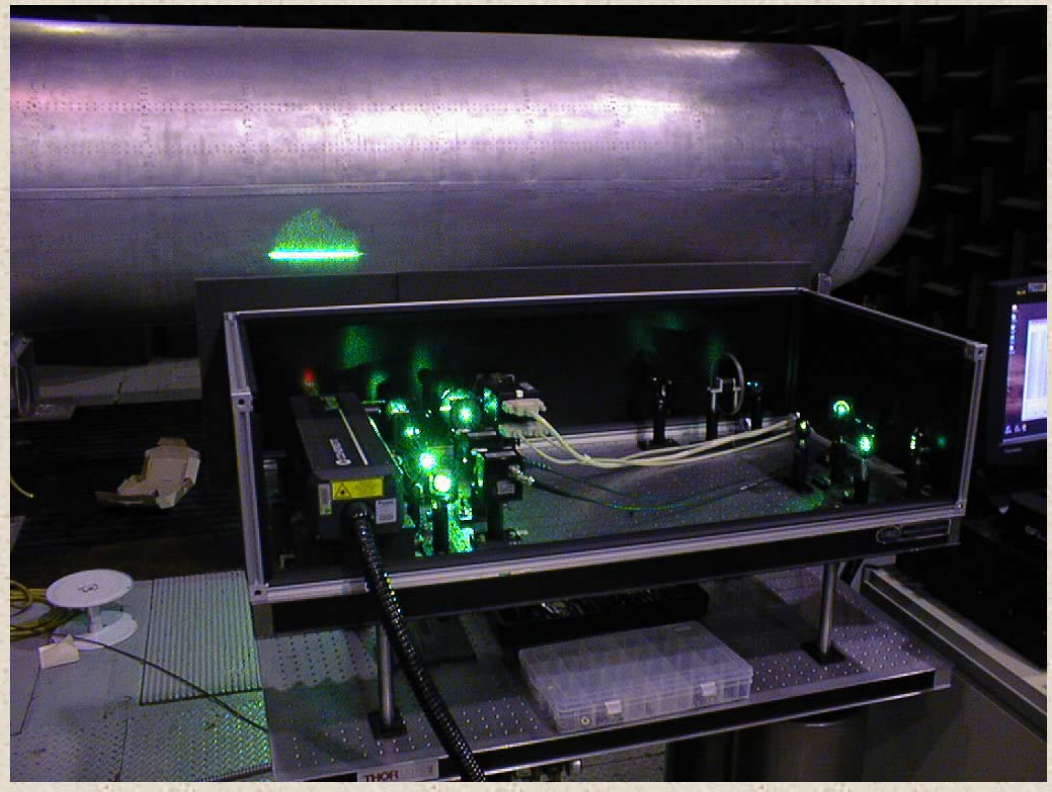


Multi-point Vibrometer Developmental Testing

Test 2: Field deployment of the linear multi-point vibrometer to obtain measurements on LaRC Aluminum Testbed Cylinder (ATC)

Objective

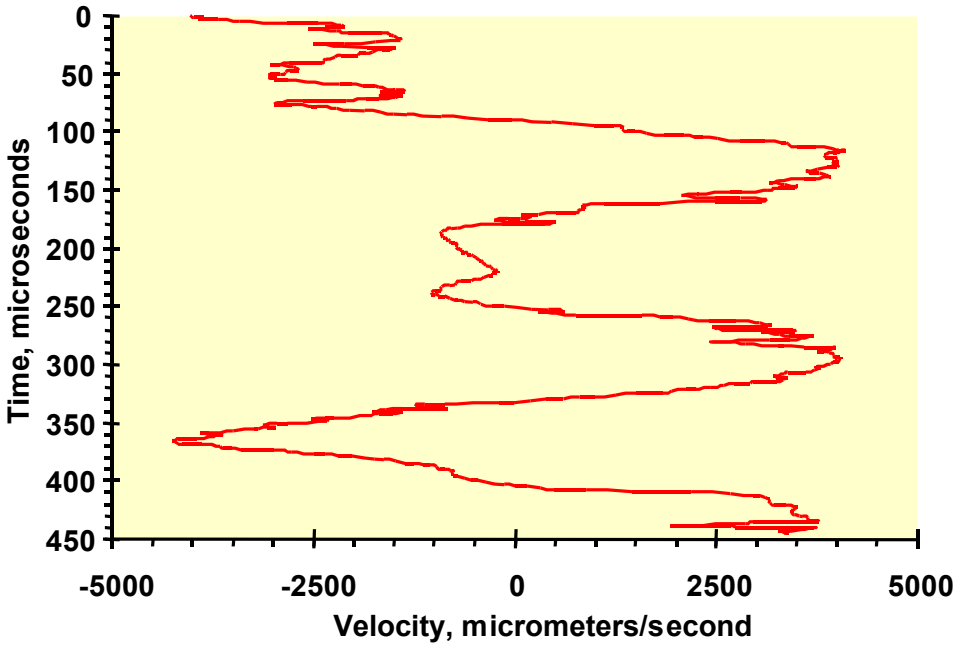
- Examine instrument robustness
- Obtain vibration measurements across a single "bay"
- Apply impulse inputs
- Measure the time-dependent surface wave propagation



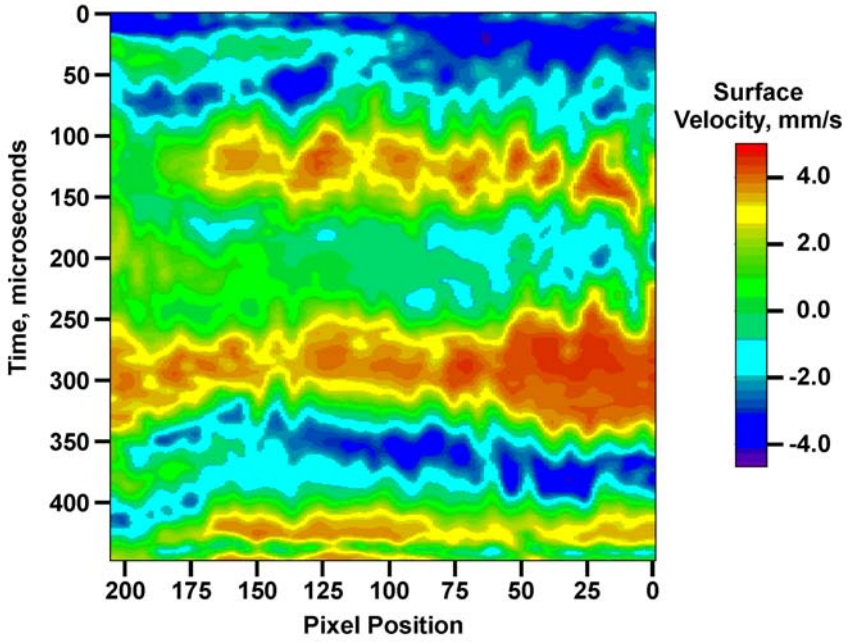
Multi-point vibrometer configured to measure ATC surface vibrations. Measurement line length = 16 in.

Tracking Time-dependent Surface Waves

- Response to impulse input at one end of cylinder
- Surface wave shown is after multiple structural reflections in a single bay



Time-dependent single pixel response



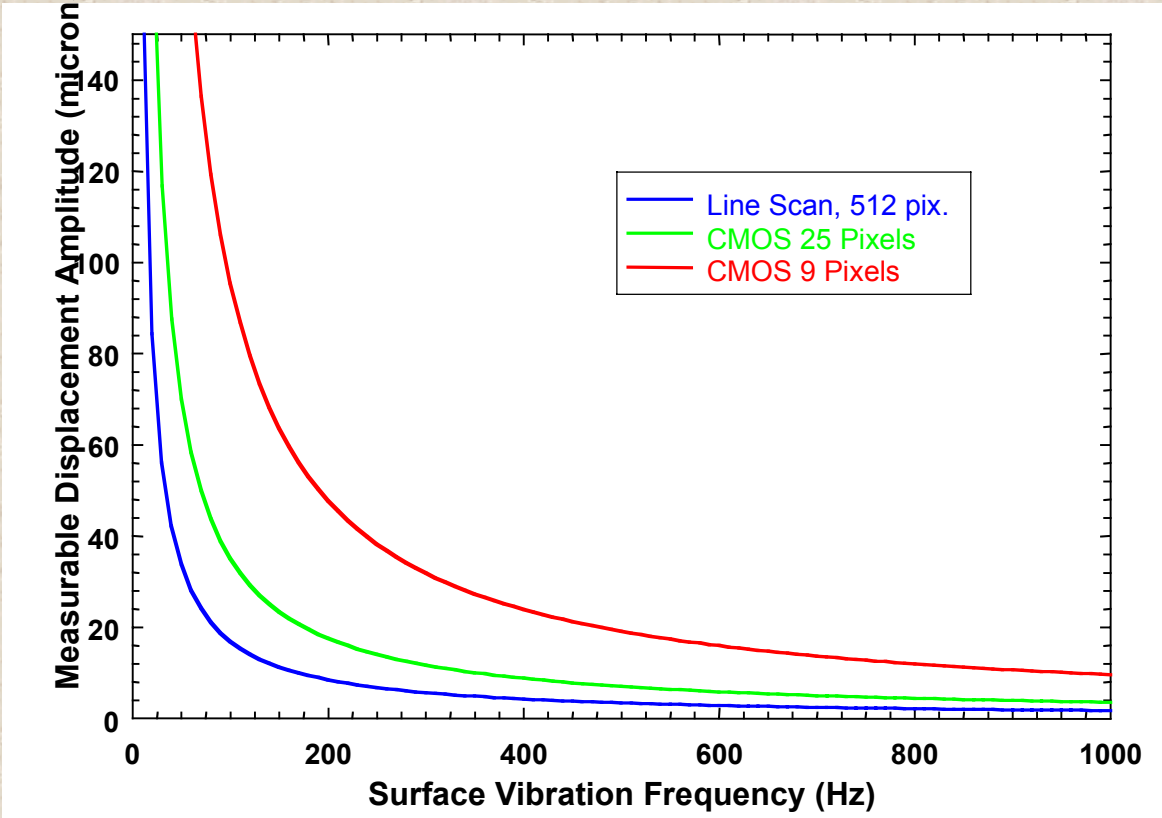
Time-dependent surface wave propagation

Multi-point Vibrometer Measurement Capabilities

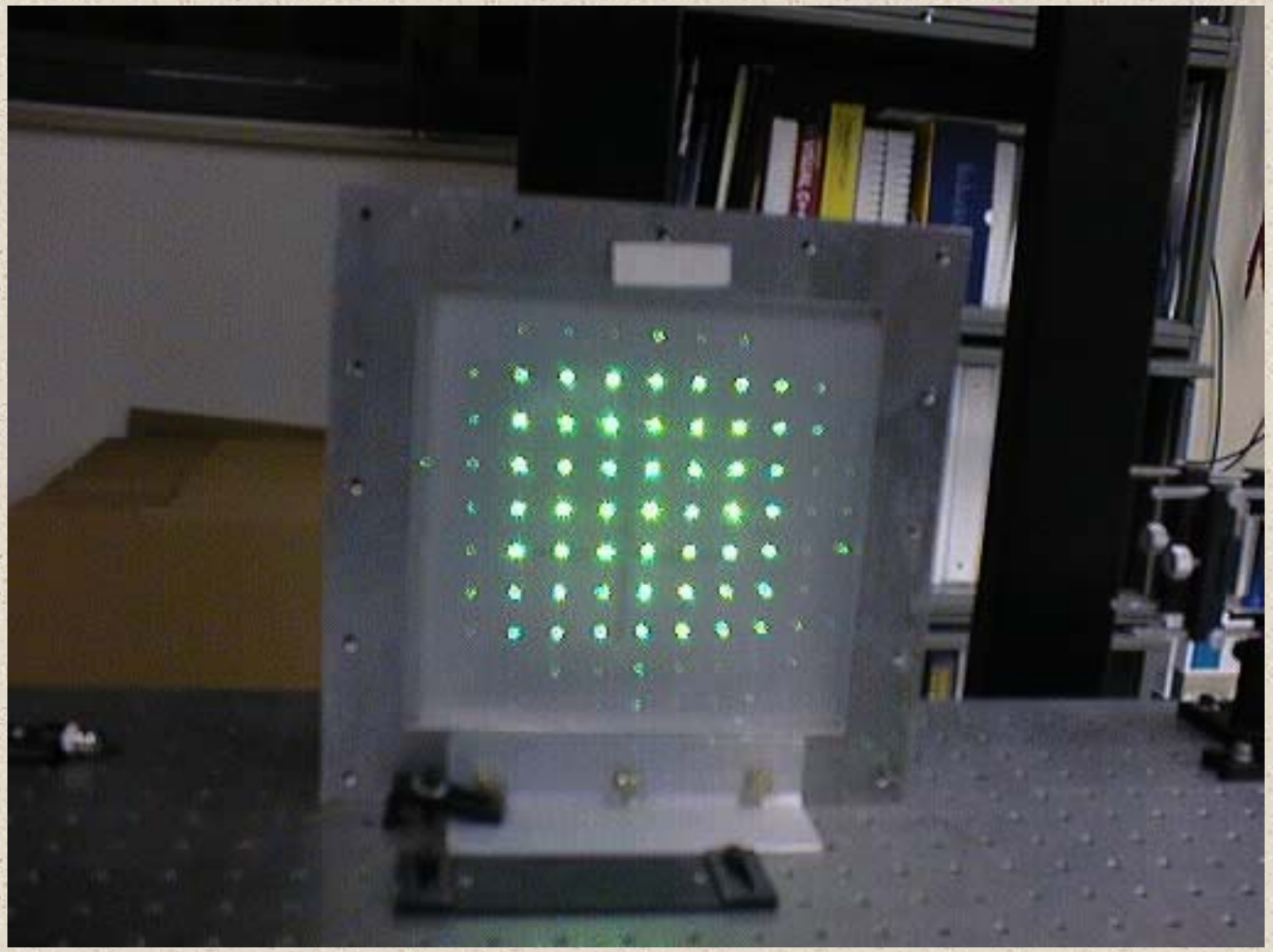
Note: We are ***NOT*** trying to match or beat performance specs of commercially available SLDV systems.

- We are trying to develop a multi-point vibrometer whose dynamic range is suitable for a majority of cases when the surface is vibrating in the "acoustic" frequency range (e.g. < 10kHz).

  - SLDV dynamic range = ± 1 meter / sec
  - MPV dynamic range = 20 – 30 mm/s
  - MPV dynamic range only limited by data acquisition speed



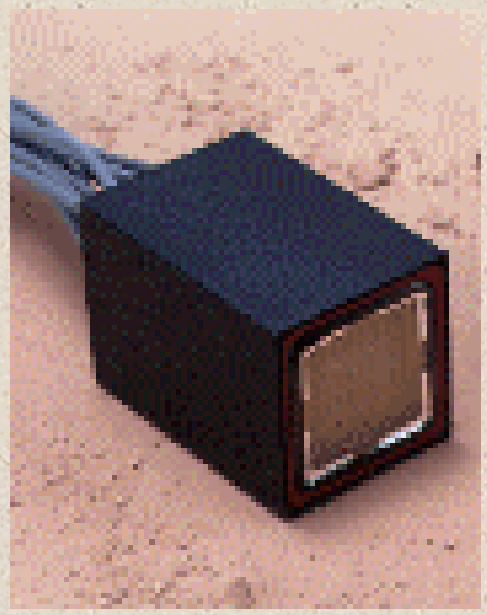
Multi-point Vibrometer 2-D Measurement Concept



7-x 7 Spot Array generated by diffractive optic

Current Development Status

- Have successfully conducted experiments using linear detector (measurements at ~512 points simultaneously)
- Currently concentrating on using 8-x 8-detector photomultiplier array for obtaining measurements over 2D array
- Continuously looking for CMOS video cameras with single-pixel addressability – we may have to fabricate our own.



8-x 8 Photomultiplier Array

LaRC-Developed “Camera” and interferometer

Discussion And Questions